

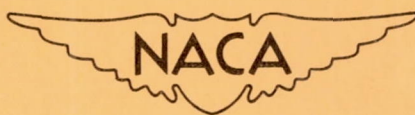
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3901

SHEAR STRENGTH AT 75° F TO 500° F OF FOURTEEN ADHESIVES
USED TO BOND A GLASS-FABRIC-REINFORCED PHENOLIC
RESIN LAMINATE TO STEEL

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SUMMARY

Fourteen adhesives used to bond a glass-fabric-reinforced phenolic resin laminate to steel were tested in order to determine their shear strengths at temperatures from 75° F to 500° F. Fabrication methods were varied in an effort to evaluate the effect of placing cloth between the faying surfaces to maintain a uniform bond line. The tests showed that sandblasting the faying surfaces to a roughness of 100 to 120 micro-inches per inch root mean square was a good method of surface preparation. Preliminary tests of all adhesives at 75° F, 250° F, and 500° F showed that one particular phenolic adhesive had a singular combination of high strength and heat resistance. Additional strength-temperature data showed that the adhesive had a shear strength of 3,400 psi at 300° F and over 1,000 psi at 500° F. The data from the preliminary tests on all the adhesives are presented in tables and in bar-graph form. The fabrication methods used with each adhesive are described.

INTRODUCTION

A heat-resistant, high-strength adhesive was needed for bonding a large-area glass-fabric-reinforced-plastic laminate to steel plate. Insufficient data were available for determining the best adhesive in the design temperature range; consequently, fourteen adhesives were tested at temperatures from 75° F to 500° F to determine their shear strengths. Inasmuch as the results may be used for other applications, the data from these tests are published herein.

The importance of maintaining a uniform bond line is one problem of adhesive use because excessive or inadequate amounts of adhesive can result in weakened bonds. Some adhesives are tape supported so that the tape acts as a spacer. However, when an unsupported adhesive is used, sometimes an auxiliary means of separating the faying surfaces must be provided. In an attempt to evaluate the suitability of using an

open-weave cloth as a spacer for unsupported adhesives, specimens for these were made in two ways: one set according to the recommendations of the adhesive manufacturers, and the other with the introduction of the open-weave cloth between the faying surfaces.

The fourteen adhesives were preliminarily tested at room temperature (approximately 75° F), 250° F, and 500° F to determine those adhesives most resistant to temperature. The data for these and subsequent tests on promising adhesives are presented in tables and graphs.

PROCEDURE

Specimen Design

The double-lap specimen used to test these adhesives is shown in figure 1. This design was chosen to eliminate possible tensile ("peeling") stresses in the adhesive that could be developed by the eccentric load on a single-lap specimen. High tensile loads on the adhesive could cause an apparent reduction in the shear strength of the adhesive (refs. 1 and 2).

A concentration of stress near the ends of the bond area is caused by shear deformation of the specimen materials. Thus, the length of the overlap can have a great effect on the average shear stress of the joint, which herein is taken to be the load divided by the total test bond area. Several theories have been developed which show that, as the length of the overlap approaches zero, the average shear stress approaches the maximum shear stress (refs. 2 and 3). However, because slight variations or faults in fabrication could cause a considerable scatter of test data for very small bond areas, a practical compromise overlap length of $\frac{3}{8}$ inch was selected for these tests.

The double-lap specimens were made by connecting two 0.125- by 1- by 13-inch strips of cold rolled steel with two 1- by 2- by $\frac{5}{32}$ -inch-thick glass-fabric laminate patches. These patches overlapped one steel strip by 1 inch and the other, by $\frac{3}{8}$ inch. The 1- by $\frac{3}{8}$ -inch overlapped areas were the test bond areas.

The laminate patches were cut from a large laminate which had been fabricated by applying pressure and heat to 17 layers of 181 glass fabric impregnated with a high-temperature-setting phenolic resin (type D, appendix A). The laminate had been cured under a pressure of 100 psia at 212° F for 1 hour and at 325° F for an additional 30 minutes. The pressure was then removed and the laminate subjected to the following postcure cycle: 4 hours at 200° F, 12 hours at 240° F, 9 hours at 320° F, 2 hours at 345° F, and 4 hours at 375° F. There was 1 hour of transient temperature between each of the aforementioned postcure temperatures.

Adhesives and Fabrication Techniques

Adhesives.- The adhesives are herein denoted by the letter symbols A to N. A brief description of each adhesive is given in appendix A, and particular fabrication data are given in appendix B.

The adhesives were selected on the basis of availability, applicability to large-area bonds, and possibility of retaining usable strength at temperatures above 250° F. Manufacturers and agencies active in adhesive development were asked to recommend adhesives that would meet the aforementioned requirements; but because the required surface temperatures were outside the range of applicability of most adhesives, few recommendations were received. Consequently, most of the adhesives tested were not specifically recommended but were speculative choices.

Surface preparation.- Two methods of surface preparation were tested. In one case both faying surfaces (steel and glass-fabric laminate) were sandblasted with clean silica lake sand to a surface-roughness value of 100 to 120 microinches per inch root mean square. In the other method, used only with one set of specimens of adhesive H, the laminate surface was prepared in the manner just described; but the steel surface was ground, cleaned, immersed in a 190° F solution containing 10 percent sulphuric acid and 10 percent oxalic acid in water, rinsed, and air dried. The acid surface preparation followed the recommendations given in reference 4.

Bond-line thickness.- A uniformly thick bond line was maintained within ± 0.002 inch of the recommended thickness where no open-weave cloth (0.005-inch leno cloth) or tape-supported adhesives were used. The distance between the faying surfaces was determined by upsetting the metal of the steel strip under the corners of the patches and then grinding the upsets to produce the bond-line thickness recommended by the manufacturer. When leno-cloth or a tape-supported adhesive was used, the bond-line thickness was determined by the thickness of the cloth or tape.

Assembly jig.- The specimens were assembled in groups of six in a specially designed mounting jig that ensured alinement along the loading axis and yet allowed the specimens to expand and contract freely during the cure and postcure heating cycles. This method averted possible damage to the bond that could be caused by thermal expansion and contraction of a restrained specimen.

Curing pressures.- Four different methods were used to maintain bonding pressure; the method was selected on the basis of the amount of pressure required. The highest pressures (200 psi and over) were obtained by using a commercial hydraulic press. In general, for pressures of about 100 psi, the specimens were clamped in the assembly jig with the laminate patches covered with a silicone rubber cushion and were placed between two

loading bars. These bars were tightened by means of thumbscrews. The pressure produced by the jig-clamping-pressure method was approximate because the operator's judgement was used to determine the correct amount of tightening. The specimens to be bonded under atmospheric pressure were placed on a metal sheet with a cutout to receive the laminate patch. The underside of the cutout was covered with a flexible plastic film. The specimens were covered with another piece of plastic film, and the air was evacuated from between the films; this caused the films to press against the laminate patch. The resulting bonding pressure was between 10 and 14 psi. For some adhesives only contact pressure was required; this pressure was obtained by pressing the parts together with the smallest force needed to ensure intimate contact between the adhesive and the faying surfaces.

Testing

The specimens were tested in a universal-type hydraulic testing machine equipped with an automatically controlled electric furnace. After the furnace had been preheated, the specimen was mounted with the test area inside the furnace and with the ends pin-connected to self-aligning yokes in the machine crossheads. The oven was then sealed around the specimen ends with damp fibrous asbestos. This test assembly is shown in figure 2. In order to measure the specimen temperature near the bond line, a thermocouple was mounted on the steel strip 1/2 inch from the test bond and connected to an intermittently printing recorder.

Approximately 15 minutes were required to raise the specimen temperature from room to test temperature. The specimen temperature was held with $\pm 10^{\circ}$ F of the nominal test temperature at all times during loading. For the preliminary tests, out of each group of six specimens, two were tested at room temperature (75° F), two at 250° F, and two at 500° F. Adhesives of type D showed exceptional heat resistance during these tests, and adhesives D₃ and D₄ were subsequently tested at other temperatures between 75° and 500° F to determine more complete strength-temperature data.

The machine loading rate was 250 pounds per minute throughout loading until failure. The maximum applied load and specimen temperature were recorded at failure.

RESULTS AND DISCUSSION

The shear strengths were determined by dividing the loads at failure by the total test bond surface area. These strengths are tabulated in table I. The mode of failure is described by listing the percentages of adhesive, cohesive, and laminate failure, which were visually estimated by examining the test bond area after failure. A summary of the tabulated

data for the results at room temperature, 250° F, and 500° F is given in bar-graph form in figure 3. This figure shows the shear stresses (average of two specimens) at failure for the preliminary tests.

The addition of leno cloth affected the bond strength, but the magnitude and whether there was an increase or decrease in strength depended upon the adhesive. No general conclusions may be drawn from these data concerning the effect of the leno cloth on small area specimens, especially since the specimens without leno cloth also had a controlled bond line.

The acid-cleaned steel surfaces corroded badly, and the bond strengths were seriously impaired. Specimens with sandblasted surfaces had good strengths. Sandblasting is a reliable method that is easily applied to large-area bonds.

At 250° F all adhesives except groups D and M had less than 2,500 psi shear strength. In particular, adhesives D₃ and D₄ combined high strength with heat resistance, and the subsequent tests showed excellent strength retention up to 200° F for D₃ and up to 300° F for D₄. Adhesive D₄ generally had a slightly lower strength at moderate temperatures (75° F to 200° F) than did D₃.

At 500° F, all adhesives except D₃ and D₄ had less than 500 psi shear strength. Adhesive D₃ varied in strength between 475 and 875 psi, whereas adhesive D₄ varied between 1,000 and 1,600 psi.

The strength-temperature data for adhesives D₃ and D₄ are plotted in figures 4 and 5, respectively. The data are identified symbolically for each group of specimens since fabrication variations had a slight effect on the bond strength.

CONCLUDING REMARKS

The high-temperature-setting phenolic resin (adhesive D) impregnated in 181 glass fabric combined high strength with heat resistance when the raw cloth was used as a tape-supported adhesive. The bonding pressure of 100 psi used during the cure of this adhesive is not excessive for many applications. However, for large bond areas, where the total force required is large, it may be more advantageous to lower the pressure to approach the atmospheric pressure used for the low-pressure specimens of the same adhesive.

Care should be exercised when extrapolating data obtained from small specimens to bond areas of other sizes. Fabrication techniques used in the

construction of these small test specimens may not be directly applicable to large-area bonds. For instance, many adhesives give off volatile matter when curing; trapped gases cause voids which have larger volumes at lower pressures and can weaken a bond.

The design of the test specimen can also affect the apparent strength of the joint. The average failing stress (as herein defined) multiplied by the bond area equals the failing load only for the specimen design used for these tests. The actual maximum shear stress in the test joint is somewhat higher than the average stress reported herein. Care should be used when extrapolating these results to joints of essentially different dimensions, since the ratio of maximum stress to average stress in the joint may exceed that for these specimens.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., September 21, 1956.

APPENDIX A

DESCRIPTION OF ADHESIVES USED IN INVESTIGATION

A description of each adhesive is given as follows:

Adhesive	Description
A	thermosetting-ethoxyline resin, supplied in stick form (Araldite Type 1; Ciba Co., Inc.)
B	moderate-temperature-setting, amine cured, 100 percent reactive epoxy resin (Epon VIII; Shell Chemical Corp.)
C	room-temperature-curing, heat-resistant, two-part adhesive consisting of an epoxy resin and a catalyst; heat cure diminishes curing time and improves shear strength (Adweld W799; Miracle Adhesive Co.)
D	primer was a high-temperature-setting phenolic resin varnish (BLL-3085 (formerly BV-17085)); to 100 parts of liquid varnish (as supplied) was added $4\frac{1}{2}$ parts of a solution made up of equal parts of ethyl alcohol, hexamethylenetetramine, and distilled water. The "adhesive" was BLL-3085 phenolic resin containing no hexamethylenetetramine. The resin was supported by style 181 woven glass fabric (112 heat cleaned) with a Volan A finish (resins by Bakelite Corp.).
E	moderate-temperature-setting mixture of thermosetting and thermoplastic ingredients mixed in solvents; believed to be polyvinyl butyral modified phenolic (Palmer 752; Palmer Products Co.)
F	moderate-temperature-setting epoxy resin, generally used as a casting resin (Hysol 6040; Houghton Labs., Inc.)
G	moderate-temperature-setting, heat-resistant mixture of phenolic and epoxy resins (FPL-710; Forest Products Lab. (see ref. 4))
H	moderate-temperature-setting epoxy resin, generally used as a casting resin (FPL-881; Forest Products Lab. (see ref. 4))

Adhesive	Description
I	high-temperature-setting, heat-resistant phenolic-acrylonitrile resin blend (Metlbond 4021 unsupported-tape adhesive, type I) used with liquid primer (Metlbond 4021, liquid, type II; Narmco Resins and Coating Co., Inc.)
J	moderate-temperature-setting epoxy resin used with a liquid hardener; supplied in paste form (Armstrong adhesive J-1151; Armstrong Cork Co.)
K	high-temperature-setting, 100 percent reactive paste of the epon family which can be set at room temperature by the addition of a curing agent, but does not develop full strength without a heat cure (Duro-Lok Paste 5201; National Adhesive Co.)
L	moderate-temperature-setting epoxide-based adhesive used with a catalyst (Epiphen XR-823; Borden Co.)
M	moderate-temperature-setting epoxy resin; two-part adhesive used with a hardener (Bondmaster NN64A; Rubber and Asbestos Corp.)
N	high-temperature-setting synthetic rubber and phenolaldehyde resins, unsupported film (Plastilock 601 Tape; B. F. Goodrich Co.)

APPENDIX B

FABRICATION TECHNIQUES

Following is a brief description of fabrication techniques used with each adhesive. Subscripts are used for identification when more than one technique is used with a given adhesive.

Adhesive A₁: The faying surfaces were sandblasted. The parts were then heated to 280° F and adhesive A was applied. The adhesive was then cured at 320° F for 2 hours under contact pressure.

Adhesive A₂: The same process was used as for A₁, except that 0.005-inch leno cloth was placed between the faying surfaces.

Adhesive B₁: The faying surfaces were sandblasted. Adhesive B was then applied and cured at 200° F for 90 minutes under contact pressure.

Adhesive B₂: The same process was used as for B₁, except that 0.005-inch leno cloth was placed between the faying surfaces.

Adhesive C₁: The faying surfaces were sandblasted. Adhesive C was applied and cured at 200° F for 20 minutes under contact pressure.

Adhesive C₂: The same process was used as for C₁, except that 0.005-inch leno cloth was placed between the faying surfaces.

Adhesive D₁: The faying surfaces were sandblasted. The parts were then heated to 212° F and adhesive D was applied. The curing cycle was 212° F for 1 hour and 325° F for 30 minutes under 100 psi pressure (jig clamping pressure). The pressure was removed and the adhesive was postcured with the following temperature cycle: 200° F for 4 hours, 240° F for 12 hours, 320° F for 9 hours, 345° F for 2 hours, and 375° F for 4 hours. There was 1 hour of transient temperature between each of the postcure temperatures. The adhesive for these specimens was obtained by squeezing heated glass fabric that had been impregnated with the resin.

Adhesive D₂: The same techniques were used as for D₁, except that 0.005-inch leno cloth was placed between the faying surfaces.

Adhesive D₃: The surfaces were sandblasted and primed with adhesive D mixed by the formula. The volatile compounds were flashed off by

placing the parts in an air-circulation oven with an air temperature of 280° F. The parts were in the oven for a maximum time of 5 minutes. The parts were then assembled with 181 glass cloth impregnated with raw resin between the faying surfaces. The assembly was placed under 100 psi pressure (jig clamping pressure) and cured with the same cure and postcure temperature cycle used for adhesive D₁.

Adhesive D₄: The same process was used as with D₃, except that atmospheric pressure was used during the curing cycle.

Adhesive E: The faying surfaces were sandblasted. Adhesive E was applied and solvent was removed at 150° F for 30 minutes. Adhesive was cured for 15 minutes at 300° F to 325° F under a pressure of 200 psi.

Adhesive F₁: The faying surfaces were sandblasted. Adhesive F was applied and cured at 140° F for 1 hour under contact pressure. Adhesive F was postcured at 320° F for 2 hours.

Adhesive F₂: The same process was used as with F₁, except that 0.005-inch leno cloth was placed between the faying surfaces.

Adhesive G₁: The faying surfaces were sandblasted. Adhesive G was applied, cured at 180° F for 20 minutes, and postcured at 280° F for 1 hour. A pressure of 490 psi was used during both cure and postcure cycles.

Adhesive G₂: The same process was used as with G₁, except that a pressure 100 psi (jig clamping pressure) was used during the cure and postcure cycles.

Adhesive H₁: The faying surfaces were sandblasted. Adhesive H was applied, cured at 200° F for 1 hour, and postcured at 300° F for 1 hour. A pressure of 100 psi was maintained during the cure and postcure cycle by means of a commercial hydraulic press.

Adhesive H₂: The same process was used as for H₁, except that 0.005-inch leno cloth was placed between the faying surfaces.

Adhesive H₃: The laminate surface was sandblasted, and the steel surfaces were acid cleaned. Adhesive H was applied, cured at 200° F for 1 hour, and postcured at 300° F for 16 hours. A pressure of 100 psi was maintained during the cure and postcure cycle by means of a commercial hydraulic press.

Adhesive I: The faying surfaces were sandblasted. The liquid primer (see appendix A) was applied and air dried for 4 to 6 hours at

room temperature. The resin adhesive was placed between the faying surfaces, and the assembly was cured at 350° F for 1 hour under 100 psi pressure (jig clamping pressure).

Adhesive J: The faying surfaces were sandblasted. The adhesive was applied and cured at 180° F for 2 hours under contact pressure.

Adhesive K₁: The faying surfaces were sandblasted. The adhesive was applied and cured at 212° F for 30 minutes under contact pressure.

Adhesive K₂: The same process was used as for K₁, except that 0.005-inch leno cloth was placed between the faying surfaces.

Adhesive L₁: The faying surfaces were sandblasted. Adhesive L was applied, cured at 120° F for 4 hours under contact pressure, and then postcured at 230° F for 30 minutes.

Adhesive L₂: The same process was used as for L₁, except that 0.005-inch leno cloth was placed between the faying surfaces.

Adhesive M₁: The faying surfaces were sandblasted. Adhesive M was applied, cured at 200° F for 1 hour under contact pressure, and the postcured at 300° F for 1 hour.

Adhesive M₂: The same process was used as for M₁, except that 0.005-inch leno cloth was placed between the faying surfaces.

Adhesive N: The faying surfaces were sandblasted. The tape-supported adhesive N was placed between the faying surfaces and cured at 350° F for 30 minutes.

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TABLE I.- AVERAGE SHEAR STRESS AT FAILURE OF FOURTEEN ADHESIVES
TESTED AT TEMPERATURES FROM 75° F TO 500° F

Adhesive	Nominal test temperature, °F	Shear stress, psi	Adhesive from steel	Type of failure, percent	
				Cohesive	Laminate
A ₁	75	2,050	75	25	---
	75	1,770	20	80	---
	250	137	80	20	---
	250	198	40	60	---
	500	14	20	80	---
	500	13	---	100	---
A ₂	75	3,170	100	---	---
	75	3,020	100	---	---
	250	348	85	15	---
	250	319	90	10	---
	500	13	100	---	---
	500	35	100	---	---
B ₁	75	3,350	---	---	100
	75	3,350	---	---	100
	250	375	100	---	---
	250	334	50	50	---
	500	143	40	60	---
	500	66	5	95	---
B ₂	75	3,040	---	---	100
	75	3,020	---	---	100
	250	551	60	40	---
	250	280	80	20	---
	500	202	30	70	---
	500	199	50	50	---
C ₁	75	1,540	50	---	50
	75	3,120	45	---	55
	250	332	100	---	---
	250	^a 328	95	5	---
	250	279	90	10	---
	500	110	75	25	---
C ₂	75	2,240	---	---	100
	75	1,605	---	40	60
	250	290	80	20	---
	250	254	90	10	---
	500	174	80	20	---
	500	161	10	90	---
D ₁	75	3,510	100	---	---
	75	3,590	95	---	5
	250	3,140	60	---	40
	250	3,240	15	---	85
	500	250	90	10	---
	500	258	75	25	---
D ₂	75	2,700	90	10	---
	75	3,210	85	15	---
	250	3,160	95	5	---
	250	2,340	30	5	65
	449	513	85	15	---
	500	343	75	25	---

^aThe loading rate was higher than 250 pounds per minute.

TABLE I.- AVERAGE SHEAR STRESS AT FAILURE OF FOURTEEN ADHESIVES

TESTED AT TEMPERATURES FROM 75° F TO 500° F - Continued

Adhesive	Nominal test temperature, °F	Shear stress, psi	Adhesive from steel	Type of failure, percent	
				Cohesive	Laminate
D ₃ Group 1	75	4,580	10	90	---
	75	3,440	5	95	---
	250	3,860	5	95	---
	250	3,050	5	95	---
	500	624	10	90	---
	500	475	10	90	---
D ₃ Group 2	202	4,020	5	---	95
	208	4,470	---	40	60
	299	3,400	---	20	80
	300	3,440	---	---	100
	401	1,775	20	5	75
	410	1,463	10	5	85
D ₃ Group 3	75	4,860	10	85	5
	75	4,950	---	100	---
	250	3,590	100	---	---
	250	3,320	50	50	---
	500	874	5	25	70
	500	759	---	---	100
D ₄ Group 1	75	3,860	50	50	---
	183	3,120	50	50	---
	225	3,070	50	50	---
	306	2,800	50	50	---
	345	2,910	50	50	---
	504	1,052	50	50	---
D ₄ Group 2	75	3,910	50	50	---
	186	3,500	50	50	---
	271	3,050	50	50	---
	345	2,990	50	50	---
	390	2,100	50	50	---
	421	1,870	50	50	---
D ₄ Group 3	143	3,490	50	50	---
	220	2,840	50	50	---
	273	3,400	50	50	---
	306	3,120	50	50	---
	455	1,420	50	50	---
D ₄ Group 4	126	3,270	50	50	---
	156	2,940	50	50	---
	226	2,980	50	50	---
	374	2,320	50	50	---
	444	1,418	50	50	---
	475	1,100	50	50	---
D ₄ Group 5	135	3,340	50	50	---
	198	3,440	50	50	---
	374	2,370	50	50	---
	400	1,770	50	50	---
	465	1,785	50	50	---
	492	1,582	50	50	---

TABLE I.- AVERAGE SHEAR STRESS AT FAILURE OF FOURTEEN ADHESIVES

TESTED AT TEMPERATURES FROM 75° F TO 500° F - Continued

Adhesive	Nominal test temperature, °F	Shear stress, psi	Adhesive from steel	Type of failure, percent	
				Cohesive	Laminate
E	75	2,300	---	95	5
	75	2,830	---	75	25
	250	324	10	90	---
	250	293	20	80	---
	500	204	---	95	5
	500	174	---	100	---
F ₁	75	2,780	10	---	90
	75	2,660	10	---	90
	250	1,650	100	---	---
	250	1,650	100	---	---
	500	171	85	15	---
F ₂	75	3,980	70	30	---
	75	3,980	85	15	---
	250	1,620	25	75	---
	250	1,206	80	20	---
	500	196	35	65	---
	500	187	45	55	---
G ₁	75	3,120	70	---	30
	75	2,880	20	---	80
	250	1,220	40	40	20
	250	1,710	35	15	50
	500	350	15	---	85
	500	332	5	20	75
G ₂	75	3,230	15	5	80
	75	3,060	10	10	80
	250	2,170	5	---	95
	250	2,280	5	---	95
	500	123	---	---	100
	500	395	---	45	55
H ₁	75	4,100	50	50	---
	75	3,620	25	75	---
	250	1,080	100	---	---
	250	1,520	100	---	---
	500	135	100	---	---
	500	125	95	5	---
H ₂	75	3,280	85	15	---
	75	3,160	90	10	---
	250	1,300	85	15	---
	250	1,370	85	15	---
	500	167	95	5	---
	500	171	90	10	---
H ₃	75	^b 1,490	100	---	---
	75	^b 1,590	100	---	---
	75	^b 2,340	100	---	---
	75	^b 1,610	100	---	---
	75	^b 1,390	100	---	---
	75	^b 1,530	100	---	---

^bCorrosion of the steel caused one side of the specimen to fail early. The listed values are for the single shear strength of the remaining side.

TABLE I.- AVERAGE SHEAR STRESS AT FAILURE OF FOURTEEN ADHESIVES

TESTED AT TEMPERATURES FROM 75° F TO 500° - Concluded

Adhesive	Nominal test temperature, °F	Shear stress, psi	Adhesive from steel	Type of failure, percent	
				Cohesive	Laminate
I	75	2,100	---	85	15
	75	2,110	---	100	---
	250	960	100	---	---
	250	956	100	---	---
	500	415	90	---	10
	500	384	100	---	---
J	75	3,830	10	90	---
	75	3,990	30	70	---
	250	312	20	80	---
	250	297	20	80	---
	500	116	100	---	---
K ₁	75	3,260	10	90	---
	75	3,680	10	90	---
	250	^c 119	---	---	---
	250	^c 132	---	---	---
K ₂	75	3,380	50	50	---
	75	3,240	50	50	---
	250	^c 168	---	---	---
	250	^c 174	---	---	---
L ₁	75	4,490	85	15	---
	75	3,700	90	10	---
	250	308	100	---	---
	250	405	100	---	---
	500	28	---	100	---
	500	0	---	100	---
L ₁	75	2,360	60	40	---
	75	3,690	65	35	---
	250	407	80	20	---
	250	429	85	15	---
	500	44	---	100	---
	500	42	---	100	---
M ₁	75	4,450	---	50	50
	75	4,510	---	50	50
	250	1,890	60	20	20
	250	2,780	60	20	20
	500	257	90	10	---
	500	268	90	10	---
M ₂	75	4,100	---	50	50
	75	4,350	---	50	50
	250	2,700	---	50	50
	250	2,590	---	50	50
	500	284	100	---	---
	500	337	100	---	---
N	75	1,460	^d 10	---	---
	75	1,680	(^d)	---	---
	250	1,030	^d 50	---	---
	250	1,190	^d 10	---	---
	500	220	100	---	---
	500	179	100	---	---

^cAdhesive melted and smoldered.^dThe remaining percentage was an adhesive failure from the laminate.

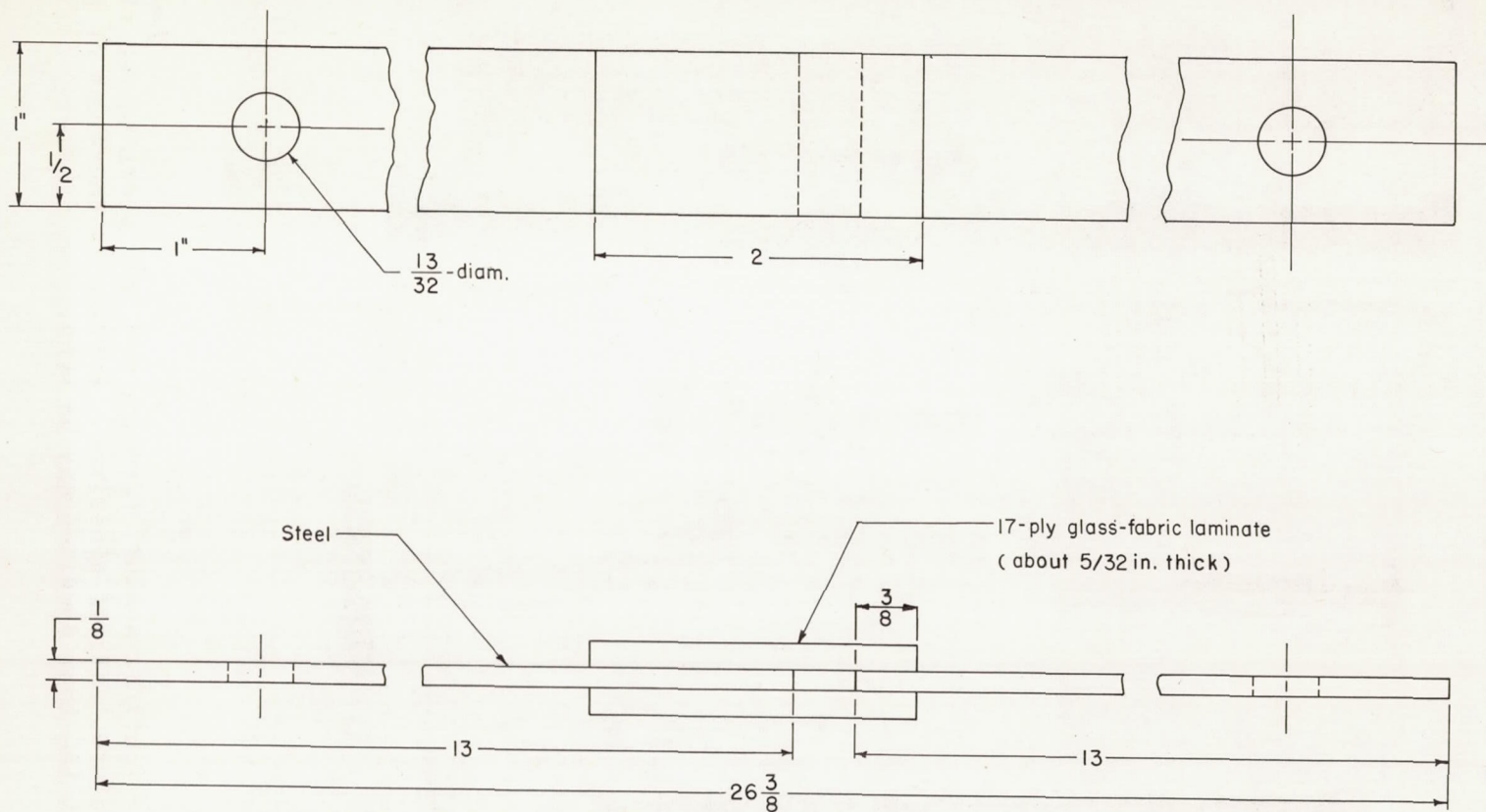
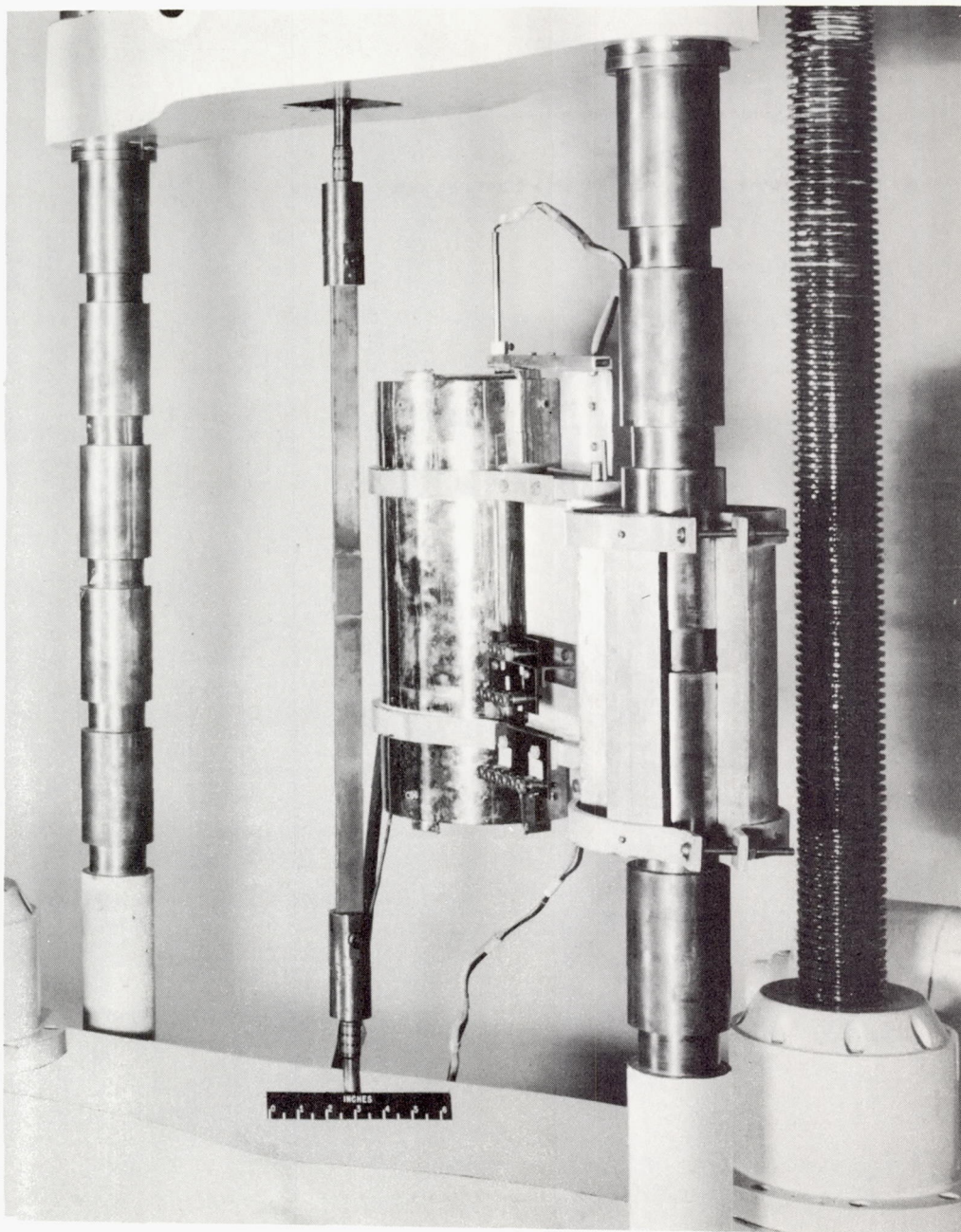
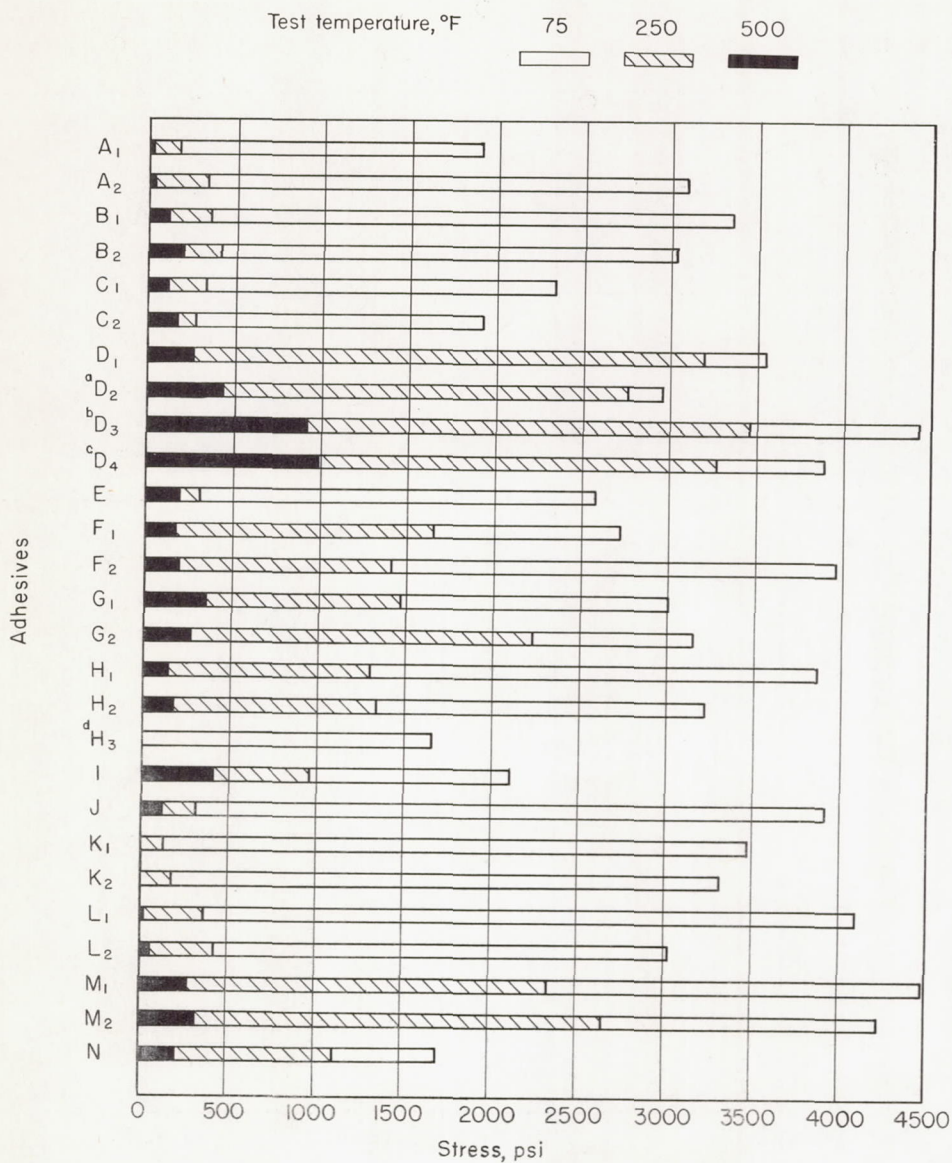


Figure 1.- Double-lap specimens for shear tests of adhesives used to bond glass-fabric-reinforced laminates to steel. All dimensions are in inches.



L-92272.1
Figure 2.- Testing machine, furnace, and test specimen for elevated temperature tests of adhesives. Furnace is shown out of position so that the test specimen may be seen.



^aOnly one specimen tested at 500° F.

^bAveraged values of four specimens.

^cValues estimated from figure 5.

^dAverage value of six specimens tested at room temperature only; single lap results.

Figure 3.- Comparison of shear strengths at 75° F, 250° F, and 500° F of adhesives used to bond glass-fabric-reinforced laminates to steel. Values are averages of two specimens.

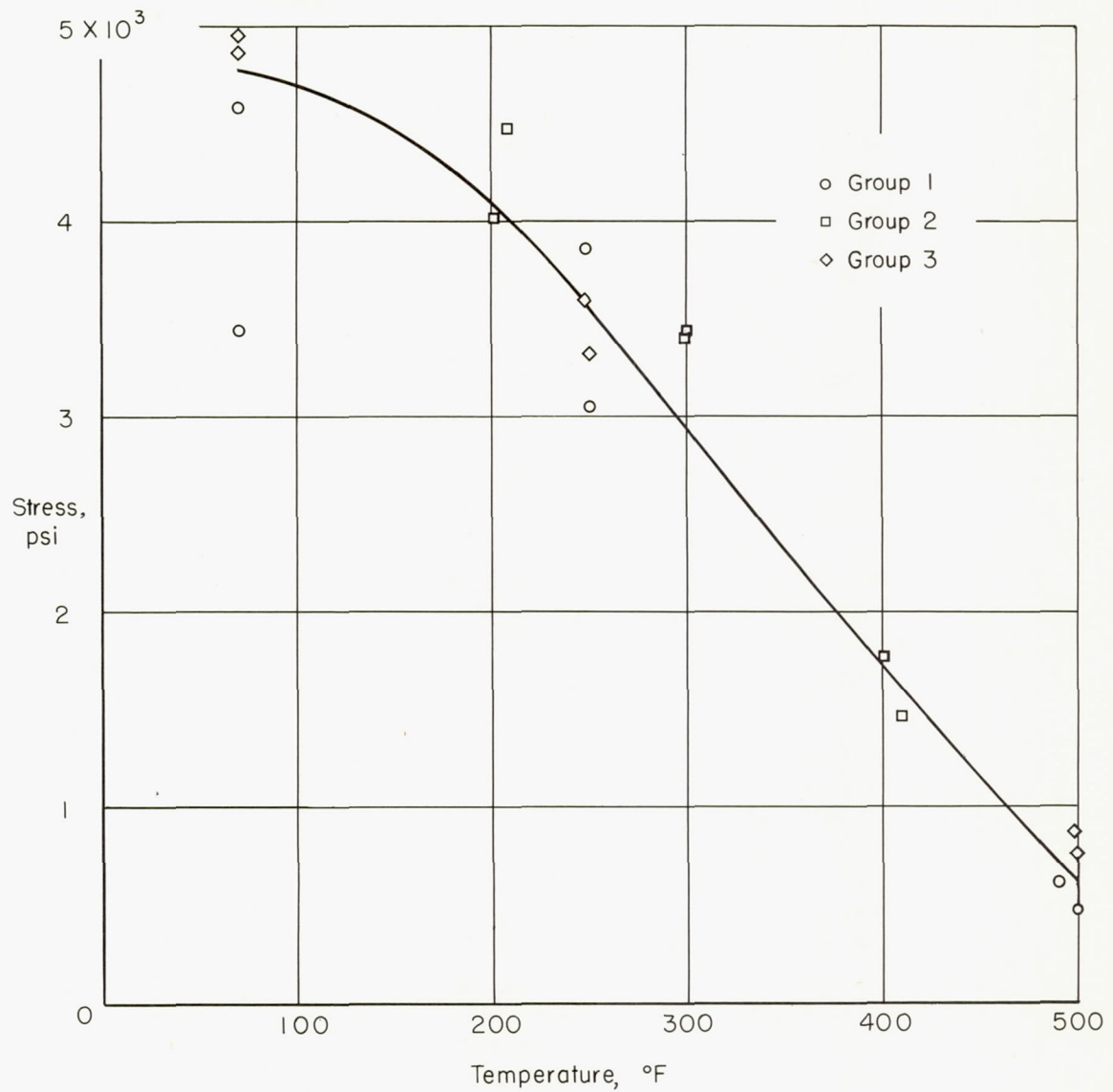


Figure 4.- Variation of shear strength with temperature of adhesive D3.

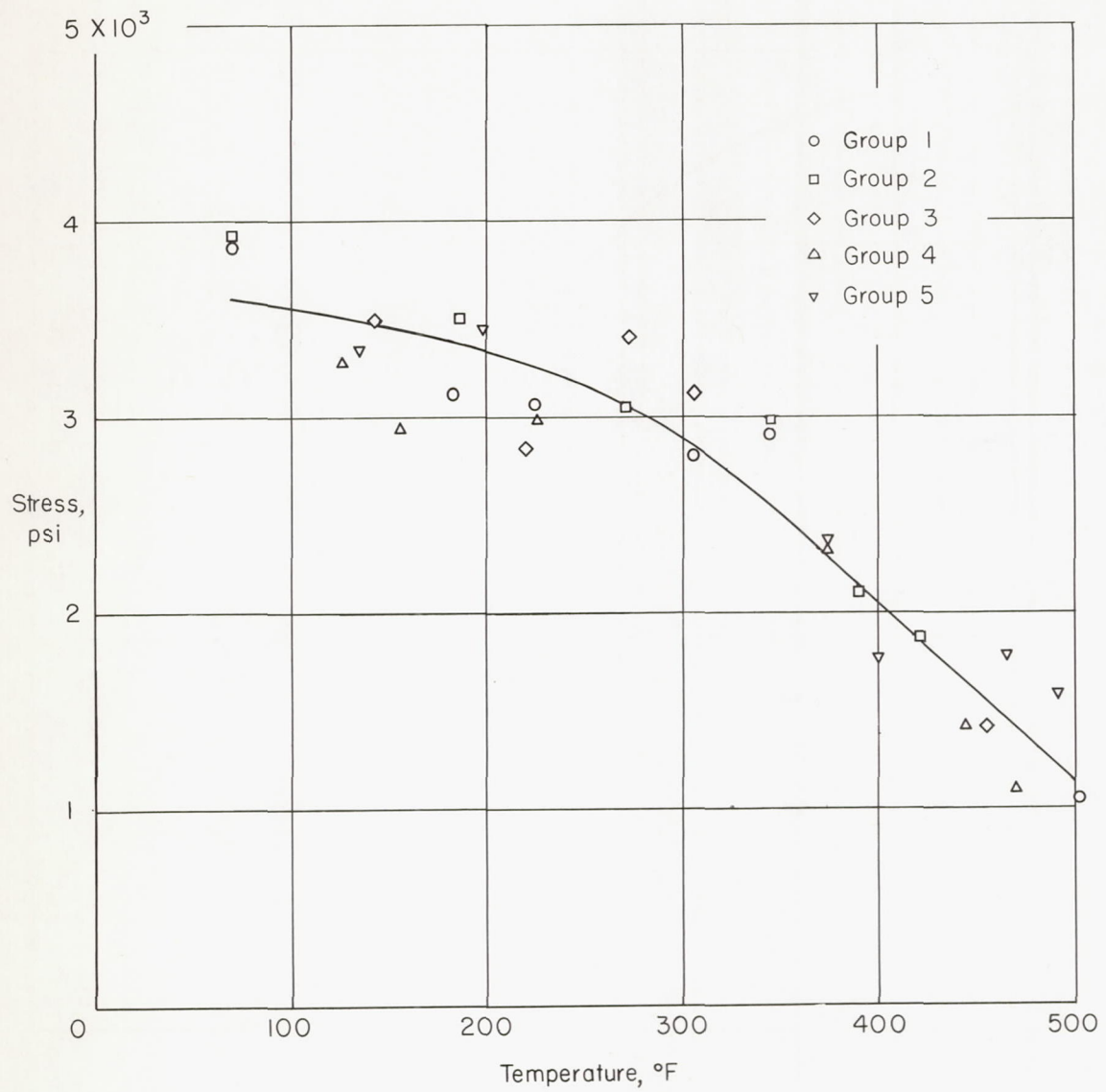


Figure 5.- Variation of shear strength with temperature of adhesive D4.